The Random Walk of Photons Inside the Sun

Yazeed Al-Rashed

under the direction of
Prof. Edmund Bertschinger
Head of Astrophysics, MIT. Kavli Building for Astrophysics and Space Research.

Research Science Institute
August 1, 2006

Abstract

The path of photons across the universe greatly assists in the study of the universe's past. This research centered on the creation and annihilation of photons dating back to the Big Bang. With special focus on the path of photons from the core of the Sun to its surface and the particles that crosses its path. The research showed that a single photon could take as much as millions of years to complete that journey; the reason for that is that it collides with particles in its path (mainly *electrons*), causing the photon to change its heading. This same pattern continues until the photon reaches the surface of the Sun, then resumes its journey tohrough the cosmos.

1 A Brief History of Light

Light can be scientifically defined as the electromagnetic radiation of any wavelength, which is broader and more advanced than the general idea on light as *visible* light only. According to the definition used, light includes Gamma rays, X-rays, ultraviolet rays, the visible spectrum, infrared rays, Terahertz radiation, microwaves, and radio waves. One specific paradox has perplexed the minds of many of the most profilic physicists in history, the precise nature of light. The question *"Is light a wave or a particle?"* is one of the key questions of modern physics.

Rene Decartes explained light as a disturbance of the plenum (the continuos substance which the universe was composed).Pierre Gassendi was the first to propose a particle theory of light, which he published in the 1600's. Isaac Newton studied Gassendi's work at an early age, but preferred Decartes' theory of the *plenum*. He clarified in his *Hypothesis of Light* in 1675 that light was composed of corpuscles, or particles of matter which were emitted in all directions from a source. One of his arguments against the wave theory was that waves were known to bend around obstacles, while light travelled only in straight lines. However, he did explain the diffraction of light by stating that a light particle could create a localized wave in the aether. One fault in Newton's theory was that it could only explain refraction by incorrectly assuming that light accelerated upon entering a denser medium, because the gravitational pull was greater.Newton published the final version of his theory in his *Opticks* in 1704.

Before the 18th century however, most early physicists inclined to describe light as a wave. In the 1600s, Robert Hooke published a wave theory of light. Christian Huygens worked out his own wave theory in 1678, and also published it in his *Treatise on Light* in

1690. He proposed tht light was emitted in al directions as a series of waves in a medium called *luminiferous aether*, and because waves were unaffected by gravity, it was assumed that they slow down when entering a denser medium. Thomas Young also added his own chapter in the 18th century, when he discovered in his Double-Slit experiment that light interferes in a similar way to interference in sound waves. He also discovered the possiblilty of polarizing light. In addition to that, he correctly stated that the reason for the difference in the colors of visible light was the difference in wavelengths. Euler was another supporter of the wave theory. He explained in *Nova theoria lucius et colorum* that diffraction would be more easily explained by a wave theory. Fresnel and Simeon Denis Poisson also produced convincing arguments in favour of the wave theory. The strongest argument proposed against the particle theory was the speed of light in denser media. Newton's theory stated that the speed of light would increase when it enters a denser medium. However when the first accurate measurement of the speed of light in 1850 by Leon Foucault showed that the speed of light actually decreases in denser media than the one it was travelling in, helping to finally overturn Newton's particle theory.

One of the weaknesses of the wave theory was that light waves - like sound waves- would need a medium for transmission. A hypothetical substance called luminiferous aether (mentioned previously) was proposed, but was then refuted by the *Michelson Morley experiment.* James Clerk Maxwell, inspired by Faraday, studied electromagnetic radiation and light, whih led to his discovery that self-propogating electromagnetic waves would travel through space at a contant speed, which is equal to the previously mesured speed of light. From this, he concluded that light was a form of electromanetic radiation. The first publication of these results was in 1962 in *On Physical Lines of Force.* In 1873, *A Treatise on Electricity and Magnetism* was published. It contained a full mathematical description of the behaviour of electric and magnetic fields (which are still known as *Maxwell's equations.*

The wave theory of light was accepted until the late 19th century, when Albert Einstien described *the Photoelectric Effect*, by which light falling on surface causes electrons to change their momentum, ultimately causing the electron to part with the surface. That caused a revitalization of the particle theory of light. The wave-particle dillema would eventually be resolved with the development of *wave-particle duality.* First described by Albert Einstein based on his work on the photoelectric effect and Max Planck's description of the *quantum theory*, the general theory states that everything has both a particle nature and a wave nature. It was previously assumed that the particle nature is more clear in large-mass objects, until Louis de Broglie's experiment in 1924 that proved electrons also exhibited wave-particle duality. Einstein recieved the Nobel Prize in 1921 for his work on the wave particle duality in photons. De Broglie also recieved the Nobel Prize in 1929 for his work on extending wave-particle duality to other particles, including electrons.

2 Photons and the Development of Quantum Theory

The first person to coin the term *photon* was Max Planck in 1900, when he described quantum theory. His description generally cosiderd light to be as a particle that could exist in discrete amounts of energy only. These packets were called *Quanta*. Planck chose the name photon, to correspond with other particle being described at that time, such as electrons, protons, and neutrons. Planck was awarded the Nobel Prize in 1918 for his part in the founding of quantum theory.

In quantum physics, photons are the quantum of electromagnetic waves. Planck gave the photon the symbol γ (the lower case variation of the Greek letter *Gamma*). Photons are also symbolized by hf, which is the amount of energy in each photon. h represents Planck's constant, which is equal to blaaaa. f is the frequency of a given photon. This symbol is taken from the following formula:

$$E_f = hf = hc/\lambda$$

c = Speed of light. λ = Wavelength.

2.1 Properties of Photons

Photons are the building units of any electromagnetic wave, so by definition, they have the same characteristics as electromagnetic waves. They are fundamentalparticles; they can be created and annihilated if they interact with other particles, but they do not decay. As mentioned before, wave-particle duality is applied to photons. In vacuum, photons travel at the speed of light in vacuum, which is exactly equal to $299,792,458m/s$. That number decreases when a photon travelles through denser medium. According to special relativity, the speed of a photon is the same for all observers, regardless of their velocities. According to general relativity, photons always travel in a straight line, taking into account the curvature of spacetime.

According to quantum electrodynamics, photons have zero rest mass and zero electric charge. However, they do have energy and momentum according to Einstein's formula:

$$E = mc^2$$

2.2 Creation and Annihilation of Photons

Photons are produced in many different ways. One way is by changes occurring in the quantum state of a charged particle, such as atoms. When an atom is accelerated in any way (by heating or other methods), free electrons become bound to the atom, or an already bound electron move from one orbital to another orbital that has less energy. That causes the atom to emit light (photons). Another example of how photons are created is when an unstable nucleus produces gamma radiation while undergoing nuclear decay. Since gamma radiation is part of the electromagnetic spectrum, photons are emitted.

3 The Random Walk of Photons

When the Big Bang occurred and photons were first created, there was a large number of free particles (namely electrons) that were scatterred. The photons encounter many of these particles while moving, and when they collide, the photons deflects. Each deflection depends on the types of particles bombarded. This paper will be focusing on the same phenomena on a smaller scale.

Photons take approximately 8 minutes to reach the Earth from the Sun's photosphere. That is not the case however when a photon travel from their point of creation inside the core of the sun. It would in fact take a single photon to complete that same journey hundreds of thousands, sometimes millions of years. The interior of the sun is filled with free charged particles, mainly electron, because of all the nuclear activity inside it. When a photon is released, it will most certainly encounter a particle in its pate, and when they collide, the heading of the photon changes. The photon then continues it's journey until it encounters another particle, which causes it to change its heading again, and so on. This pattern is often called a *Random Walk*. This continues until the photon reaches the photosphere of the

Sun, then continues its trip through the cosmos unobstructed.

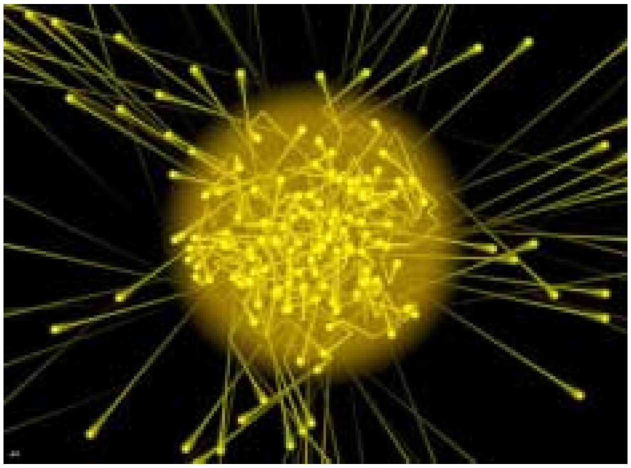

Figure 1: A Diagram Showing the Paths Taken by Photons Inside the Sun

4 Acknowledgements

I would like to thank my mentor, Professor Edmund Bertschinger, Head of the MIT Kavli Building for Astrophysics and Space Research, for all the help he could offer me. I would also like to thank Mr. Josh Carter for helping me with Matlab. My sincere appreciation goes to Dr. Chris Akerman, Dr. Jenny Sendova, and Dr. Clifford Bowman for all their time spent with me to help me in every thinkable way. I would finally like to thank the RSI and the CEE for giving me the chance to be part of this fantastic experience.

References

[1] Feynman, Richard P.: QED: The Strange Theory of Light and Matter. *Princeton Science Library*, 1988.

[2] Daintith, J.: The Facts on File Dictionary of Physics *Market House Books,* 2005.

[3] Gleick, J.: Chaos, Making a New Science. *Penguin Books,* 1987 edition.

[4] Paul, H.: Introduction to Quantum Optics. Cambridge University Press.

[5] P. A. M. Dirac: The Principles of Quantum Mechanics, 1933.

[6] Signell, P. Gilbert, K. *Characteristics of Photons*, `http://www.physnet.org/home/modules/CharofPhot.pdf`, accessed july 14, 2006.

[7] Alpher, R.: Reflections on early work on Big Bang cosmology *physics today*, August 1988.

[8] Feynman, R. Leighton, R.: The Feynman Lectures on Physics. *Addison-Wesley.* 1965.

[9] Herbert, N.: Quantum Reality, Beyond the New Physics. *Anchor Books*. 1985.

A Title of Appendix

Appendices may appear after the paper proper. Appendices may hold extra information that would interrupt the flow of the paper and that is not absolutely necessary for the reader to appreciate the work. For example, a large number of related figures or a mathematical derivation could go nicely in an appendix.